

CLAIMS

What is claimed is:

1. A cryogenic refrigeration system comprising:
an expansion nozzle having a high-pressure nozzle inlet and a low-pressure
nozzle outlet;
an expansion volume in gaseous communication with the nozzle outlet;
5 and
a compressor comprising
a reciprocating compression device operable to compress gas within
a compression volume, wherein the compression volume has an inlet port and an
outlet port,
10 a flapper inlet valve having
an inlet valve inlet, and
an inlet valve outlet in gaseous communication with the inlet
port of the compression volume, wherein the inlet valve opens when a gaseous
pressure at the inlet valve inlet is sufficiently greater than a gaseous pressure in
15 the compression volume to overcome a spring force of the flapper inlet valve, and
a flapper outlet valve having
an outlet valve inlet in gaseous communication with the
outlet port of the compression volume, and
an outlet valve outlet in gaseous communication with the
20 nozzle inlet, wherein the outlet valve opens when a gaseous pressure in the
compression volume is greater than a gaseous pressure at the outlet valve outlet
to overcome a spring force of the flapper outlet valve; and
a drive motor system in driving mechanical communication with the
compression device, wherein the compression volume is hermetically isolated
25 from the drive motor system.
2. The cryogenic refrigeration system of claim 1, wherein a void
volume of the flapper inlet valve and a void volume of the flapper outlet valve are

sufficiently small, in combination with a swept volume of the compression volume, that the compressor achieves a compression ratio of at least 15:1 in a
5 single-stage of compression.

3. The cryogenic refrigeration system of claim 1, wherein the inlet valve inlet is in gaseous communication with the nozzle outlet.

4. The cryogenic refrigeration system of claim 1, further including a heat exchanger, wherein the outlet valve outlet is in gaseous communication with the nozzle inlet through a first channel of the heat exchanger, and the nozzle outlet is in gaseous communication with the inlet valve inlet
5 through a second channel of the heat exchanger.

5. The cryogenic refrigeration system of claim 1, wherein the compression device comprises a piston suspended by a flexure.

6. The cryogenic refrigeration system of claim 1, wherein the compressor and the drive motor system are contained within a single hermetically sealed compressor housing.

7. The cryogenic refrigerator of claim 1, wherein the compression device comprises a pair of opposing compression pistons.

8. The cryogenic refrigeration system of claim 7, wherein the drive motor system comprises a linear drive motor having a respective motor coil affixed to each one of the compression pistons, and a respective magnet structure that is static.

9. The cryogenic refrigeration system of claim 7, wherein the drive motor system comprises a linear variable differential transformer providing a measurement of a position of each of the compression pistons.

10. The cryogenic refrigeration system of claim 1, wherein neither the inlet valve nor the outlet valve includes a compression spring that preloads a flapper seal.

11. The cryogenic refrigeration system of claim 1, wherein at least one of the inlet valve and the outlet valve includes a compression spring that preloads a flapper seal.

12. The cryogenic refrigeration system of claim 1, further including a cooled article in thermal communication with the expansion volume.

13. A cryogenic refrigeration system comprising:
a Joule-Thomson expansion nozzle having a high-pressure nozzle inlet and a low-pressure nozzle outlet;
an expansion volume in gaseous communication with the nozzle outlet;
5 and
a compressor comprising
a pair of opposing flexure-suspended compression pistons operable to compress gas within a compression volume, wherein the compression volume has an inlet port and an outlet port,
10 a flapper inlet valve having
an inlet valve inlet, and
an inlet valve outlet in gaseous communication with the inlet port of the compression volume, wherein the inlet valve opens when a gaseous pressure at the inlet valve inlet is sufficiently greater than a gaseous pressure in
15 the compression volume to overcome a spring force of the flapper inlet valve, and
a flapper outlet valve having
an outlet valve inlet in gaseous communication with the outlet port of the compression volume, and
an outlet valve outlet in gaseous communication with the
20 nozzle inlet, wherein the outlet valve opens when a gaseous pressure in the compression volume is greater than a gaseous pressure at the outlet valve outlet

to overcome a spring force of the flapper outlet valve; and

25 a drive motor system in driving mechanical communication with the compression pistons, wherein the compression volume is hermetically isolated from the drive motor system, and wherein the compressor and the drive motor system are contained within a single hermetically sealed compressor housing; and

30 a heat exchanger, wherein the outlet valve outlet is in gaseous communication with the nozzle inlet through a first channel of the heat exchanger, and the nozzle outlet is in gaseous communication with the inlet valve inlet through a second channel of the heat exchanger.

5 14. The cryogenic refrigeration system of claim 13, wherein a void volume of the inlet valve and a void volume of the outlet valve are sufficiently small, in combination with a volume of the compression volume, that the compressor achieves a compression ratio of at least 15:1 in a single-stage of compression.

15. The cryogenic refrigeration system of claim 13, wherein the drive motor system comprises a linear drive motor having
a respective motor coil affixed to each one of the compression pistons, and
a respective magnet structure that is static.

16. The cryogenic refrigeration system of claim 13, wherein the drive motor system comprises a hermetically isolated linear variable differential transformer providing a measurement of a position of one of the compression pistons.

17. The cryogenic refrigeration system of claim 13, wherein each of the inlet valve and the outlet valve includes a compression spring that preloads a flapper seal.

18. The cryogenic refrigeration system of claim 13, further including a cooled article in thermal communication with the expansion volume.